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FINAL REPORT

Stereo Image Registration System

30 January 1965

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SUMMARY

To permit PI scanning of large areas of photography with stereo viewing, it will be necessary to provide automatic maintenance of image registration. This project has attempted to develop means of generating error signals uniquely related to lateral positioning, rotation, and magnification errors in image registration.

The design and fabrication of breadboard equipment and subsequent testing, with test patterns and selected scene image pairs, demonstrated the feasibility of detecting and measuring stereo image registration errors. The breadboard equipment (both optical and electrical portions) lacked the required sophistication to prove the system validity when random scene image pairs were tested, but served the purpose of defining the problem parameters and areas of design requiring additional effort. When selected image pairs are tested in the system, excellent correlation between image displacement in registration and the error signals is obtained. For the majority of random image pairs, the image registration to error signal correlation is very poor or nonexistent.

The principle of measuring phase differences of the two circular scan signals to obtain error correction signals is valid. However, more effective electronic and optical systems are necessary to extract the phase differences from the signal. With the phase difference established, it is possible to detect four degrees of error: rotation, magnification, and X and Y axis displacement.

It is recommended that the program be continued in an attempt to improve the present breadboard and develop a more effective system for determining registration error from the scanned signals. The initial step of a continued program would consist of a mathematical derivation of an effective logic system. Some preliminary mathematical derivations with the input scan signals

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represented as Fourier series have indicated that it is possible to extract accurate phase information. This step would be followed by modification of the present breadboard according to findings of the mathematical derivation.

Problem areas requiring further investigation are:

a. Size of the scanning spot.

b. Size of the scanning circle.

c. Scanning format.

d. Correlation of signals.

e. Correlation of error.

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SUBJECT: Stereo Image Registration System

TASK/PROBLEM

1. Investigate possible means for automatically maintaining proper registration for stereo viewing on rear projection and direct viewing roll film viewers.

INTRODUCTION

2. Background: A major barrier to the use of stereo viewing in PI mission scanning is the difficulty of maintaining registration of the conjugate image pairs while scanning large film areas. This is particularly true for convergence photography from panoramic type cameras. The ultimate need is for automatic electro-optical accessories to maintain registration in roll film stereo viewers. These accessories would be adequate if they could maintain stereo registration while the operator scans over a scene pair after registration is established for one section of the scene.

3. Approach: This project was planned to build breadboard apparatus and explore a possible technique for physically scanning a stereo image pair and generating orthogonal error signals representing relative lateral positioning (X,Y,), rotation (θ), and magnification (M) in the viewer-print relationships.

4. Breadboard Arrangement: Figure 1 is an exploded schematic view of the breadboard optical system. Further details are shown in Figures 3, 4, and 5. The electronic console (Figure 2) houses the error logic, error meters, and associated power supplies.

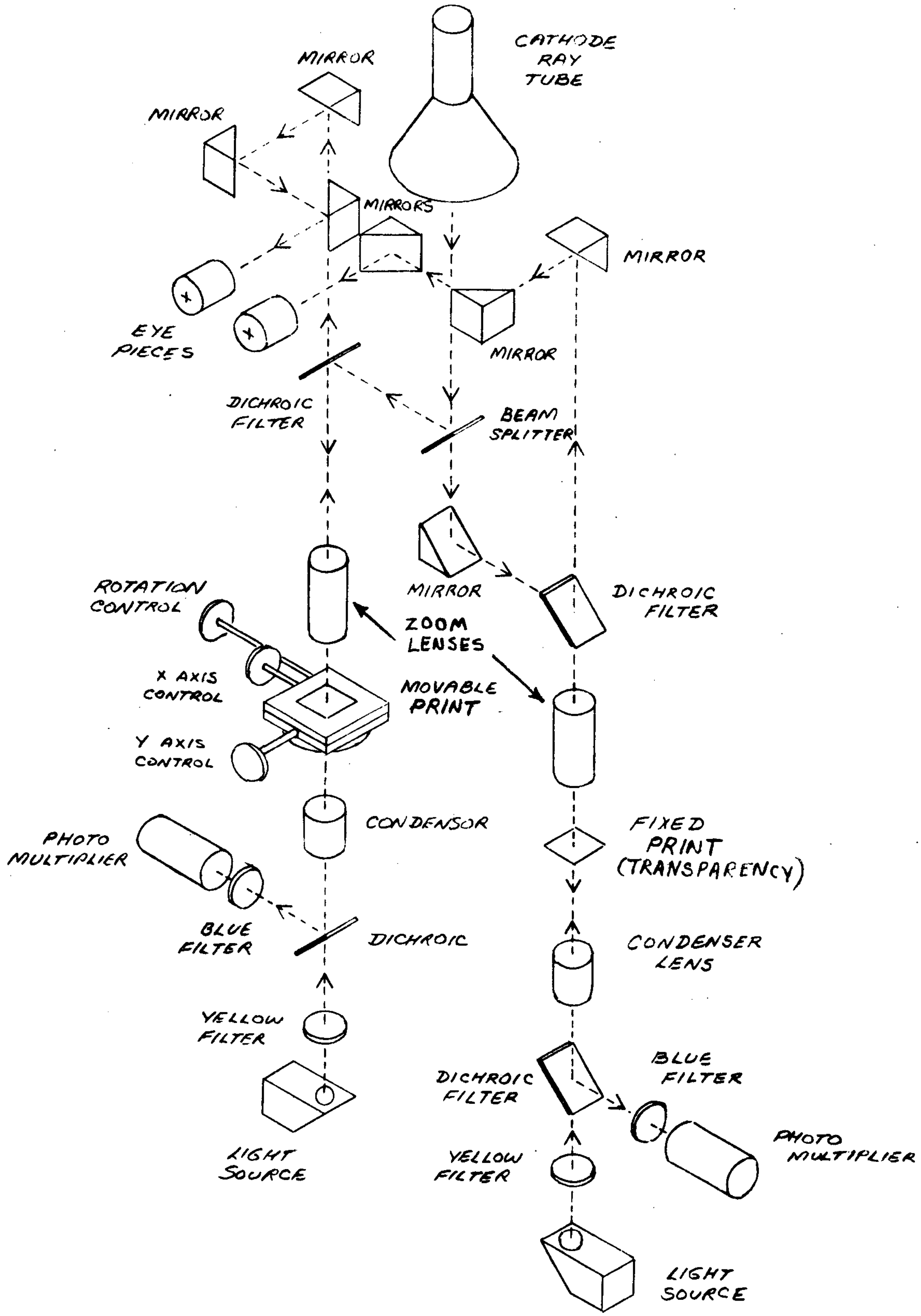

Figure 1. Stereo Registration Optical System

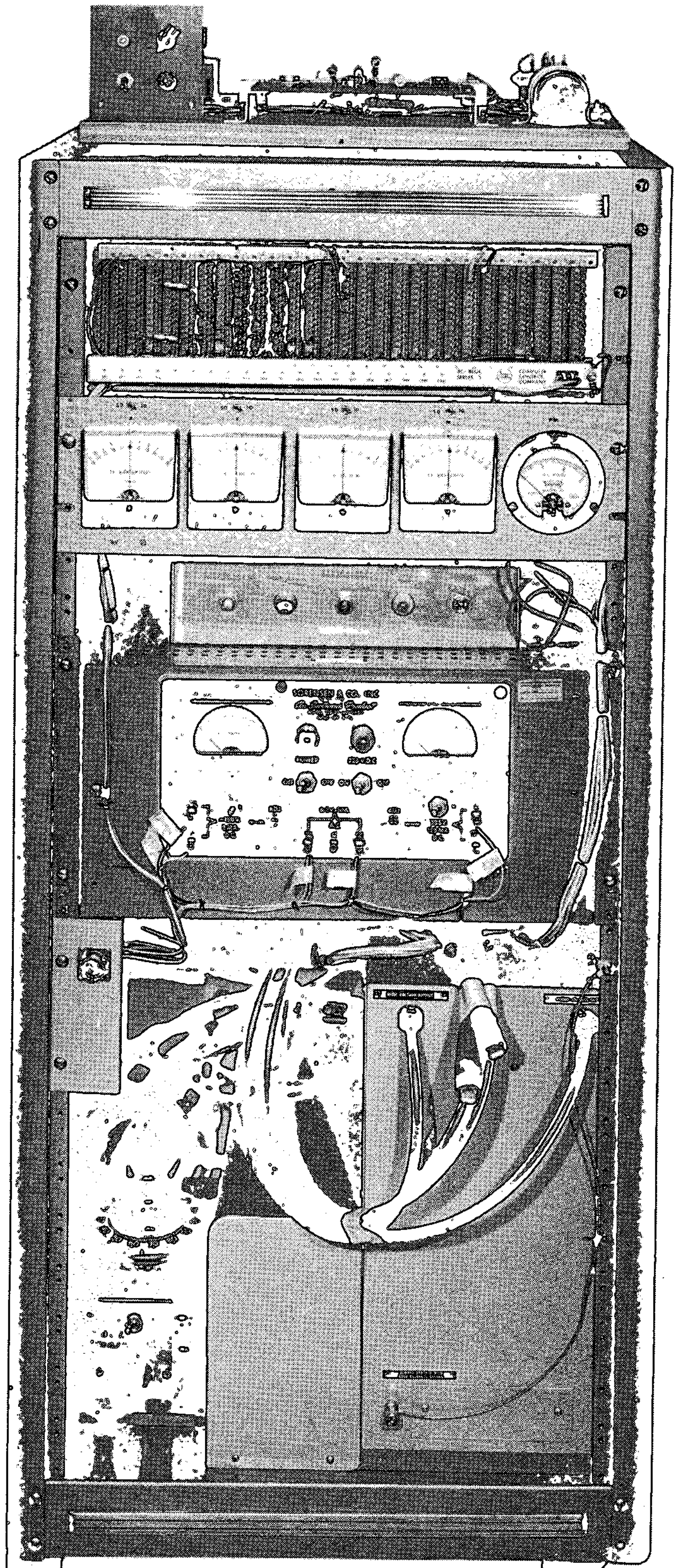

Figure 2. Electronic Console

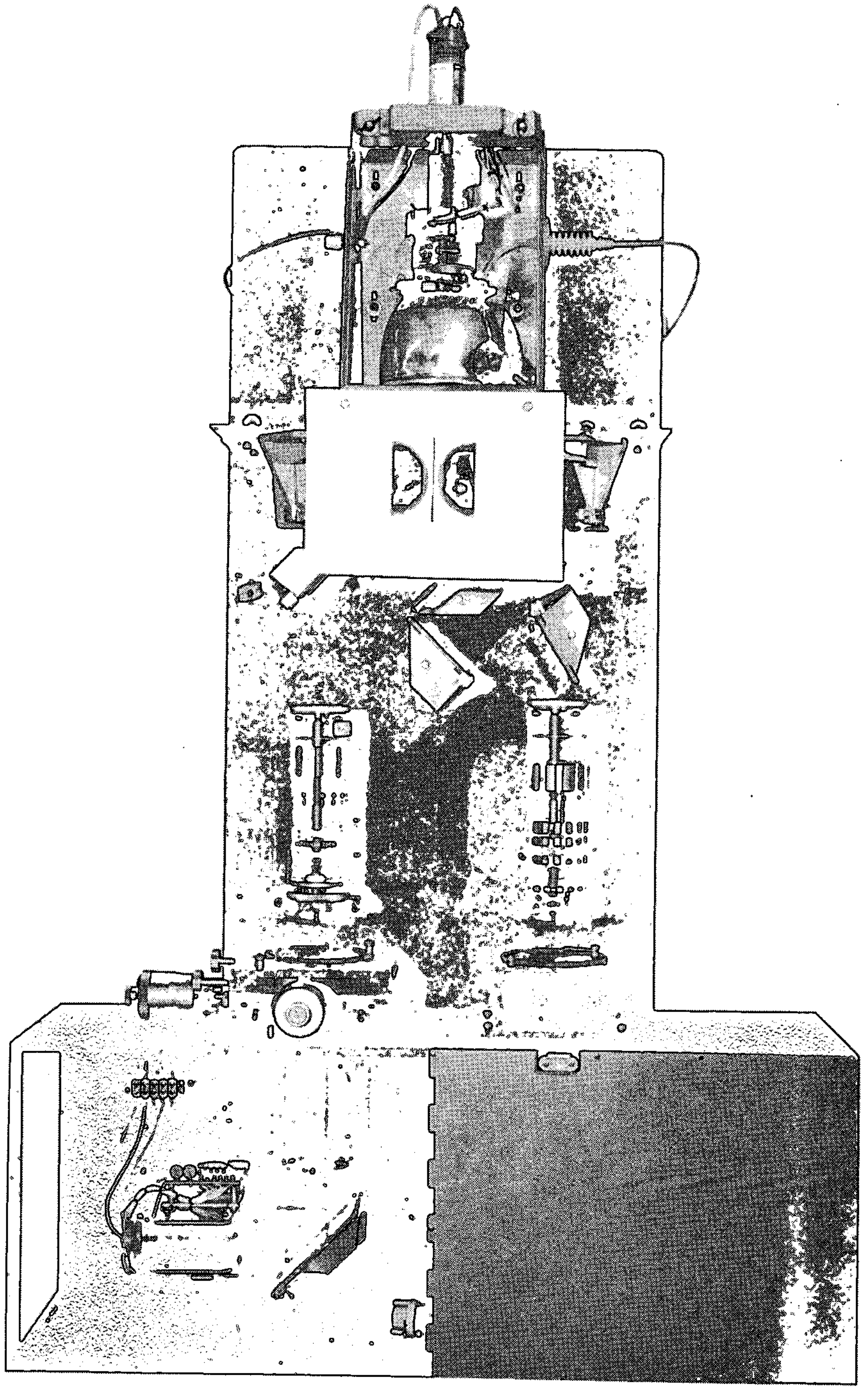

Figure 3. Optical Breadboard

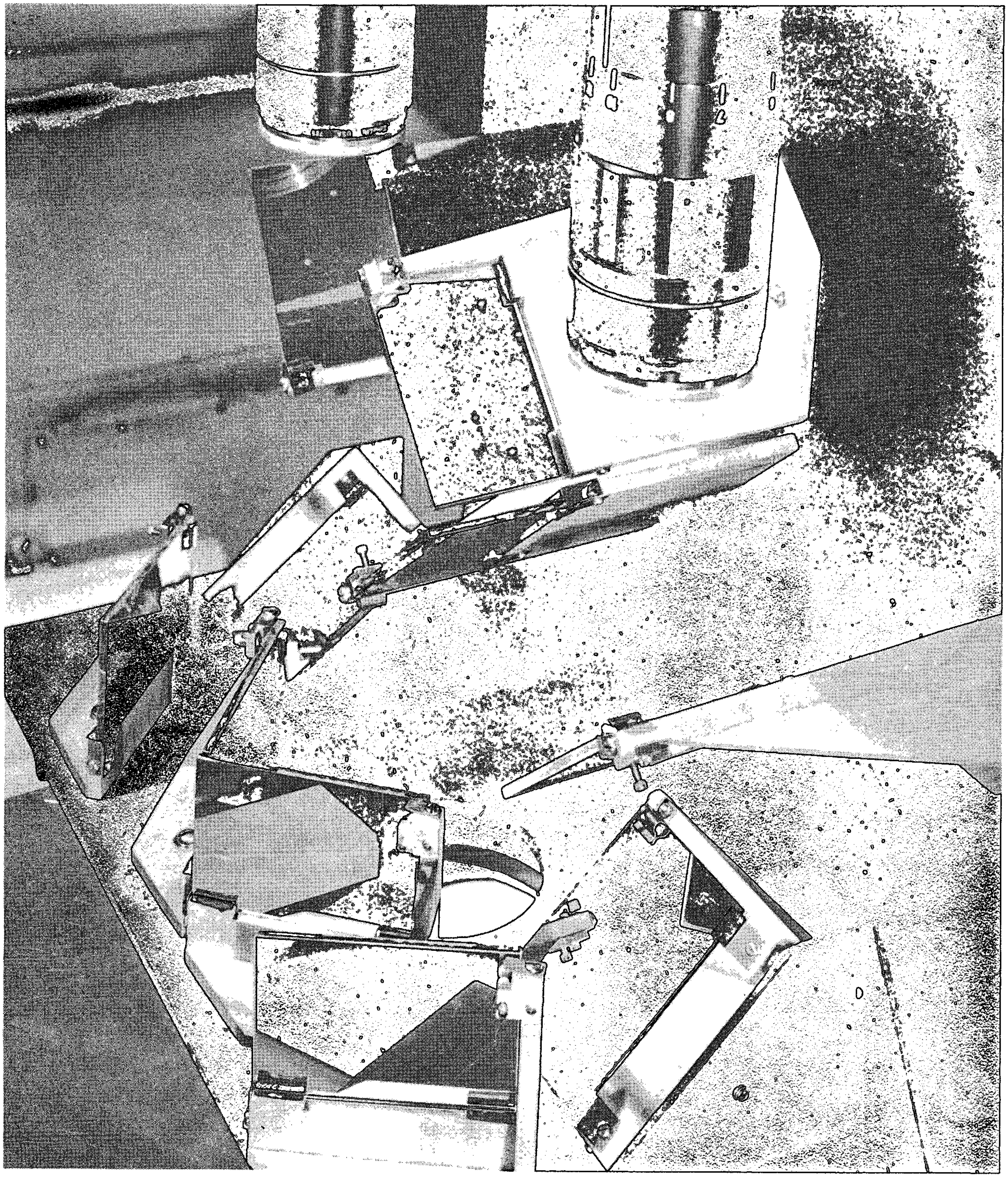

Figure 4. CRT Optics

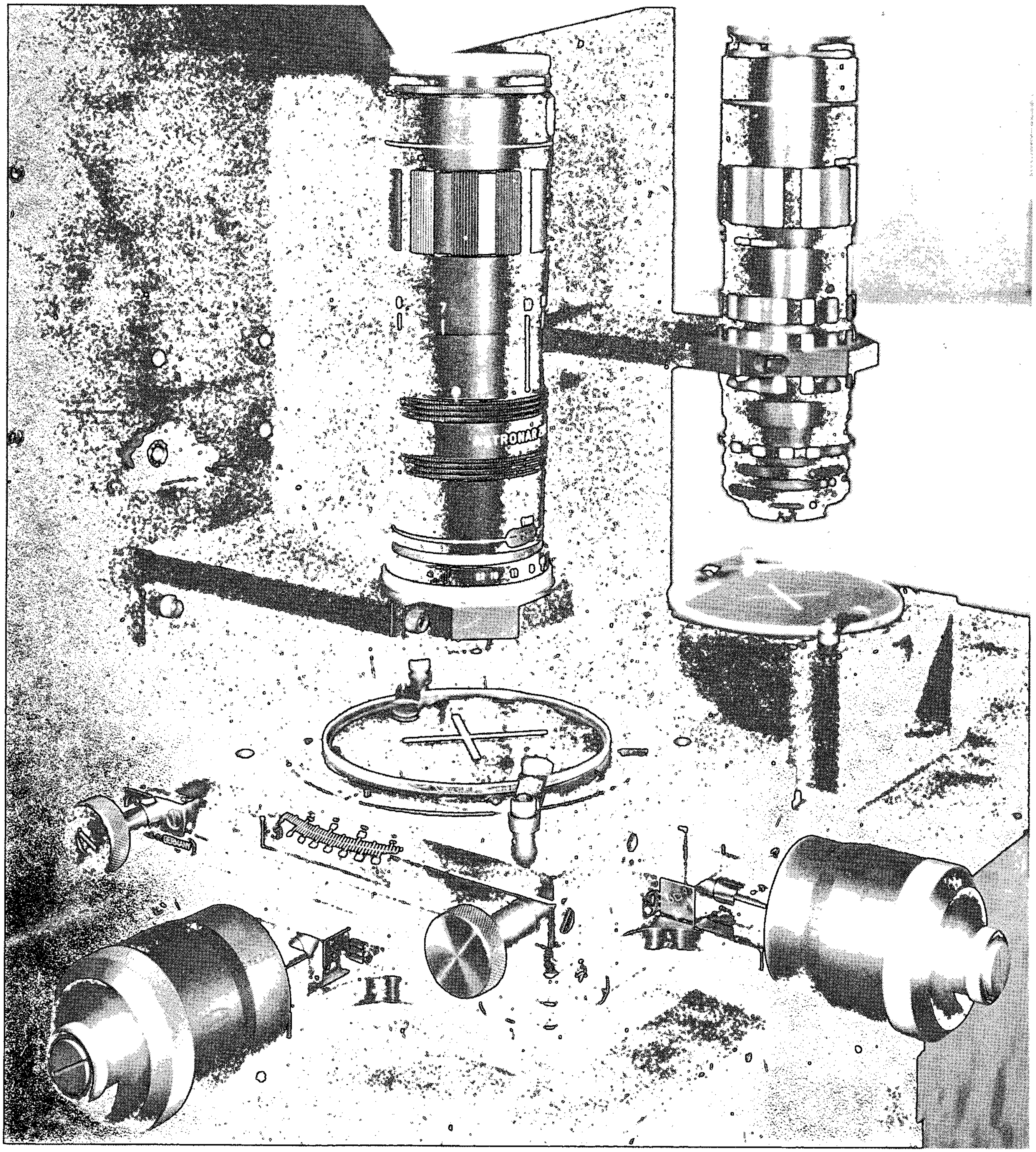

Figure 5. Position Table

a. Scanning Source: A 1.5-inch diameter circle is displayed on the face of the cathode ray tube (CRT), see Figure 6, which provides the scanning light source for the system. For this breadboard, the scanning spot moves in its circular path at a rate of 60 cycles per second. Spot size and brightness can be manually adjusted.

b. Optical System: Mirrors, dichroic filters, lenses, and a beam splitter provide both the visual observation system and the photoelectric scanning system. Blue light from the P16 phosphor CRT is used for scanning, and yellow light from filtered tungsten lamps is used for viewing. The CRT image is projected downwards onto each print of a conjugate stereo image pair through the beam splitter and the matched pair of zoom lenses with 4:1 image reduction. Two photomultiplier (PM) tubes (S11 spectral response) detect the transmitted blue light passing through the respective prints. The PM output signals vary linearly with the transmittances encountered by the CRT spot projected onto the film. Visual observation of the stereo image pair uses the yellow filtered sources under the prints, imaging through the same lenses as for the CRT image and finally to the pair of eyepieces. The effects of a given adjustment of print position or zoom lens magnification upon visual effect and upon PM signals may be compared.

c. Logic: Registration error signals, sensed in the logic, are based upon the relationship of the zero volts crossing of the two scan signals.

(1) The logic generates a magnification error signal (Figure 7) if the pulse width of one PM signal is wider than the pulse width of the other PM signal. The narrower pulse must fall completely within the wider pulse to generate the error signal.

(2) The logic generates a rotation error signal (Figure 8) if the pulse of one PM is displaced in phase from the other. The two pulses must overlap each other to generate the error signal.

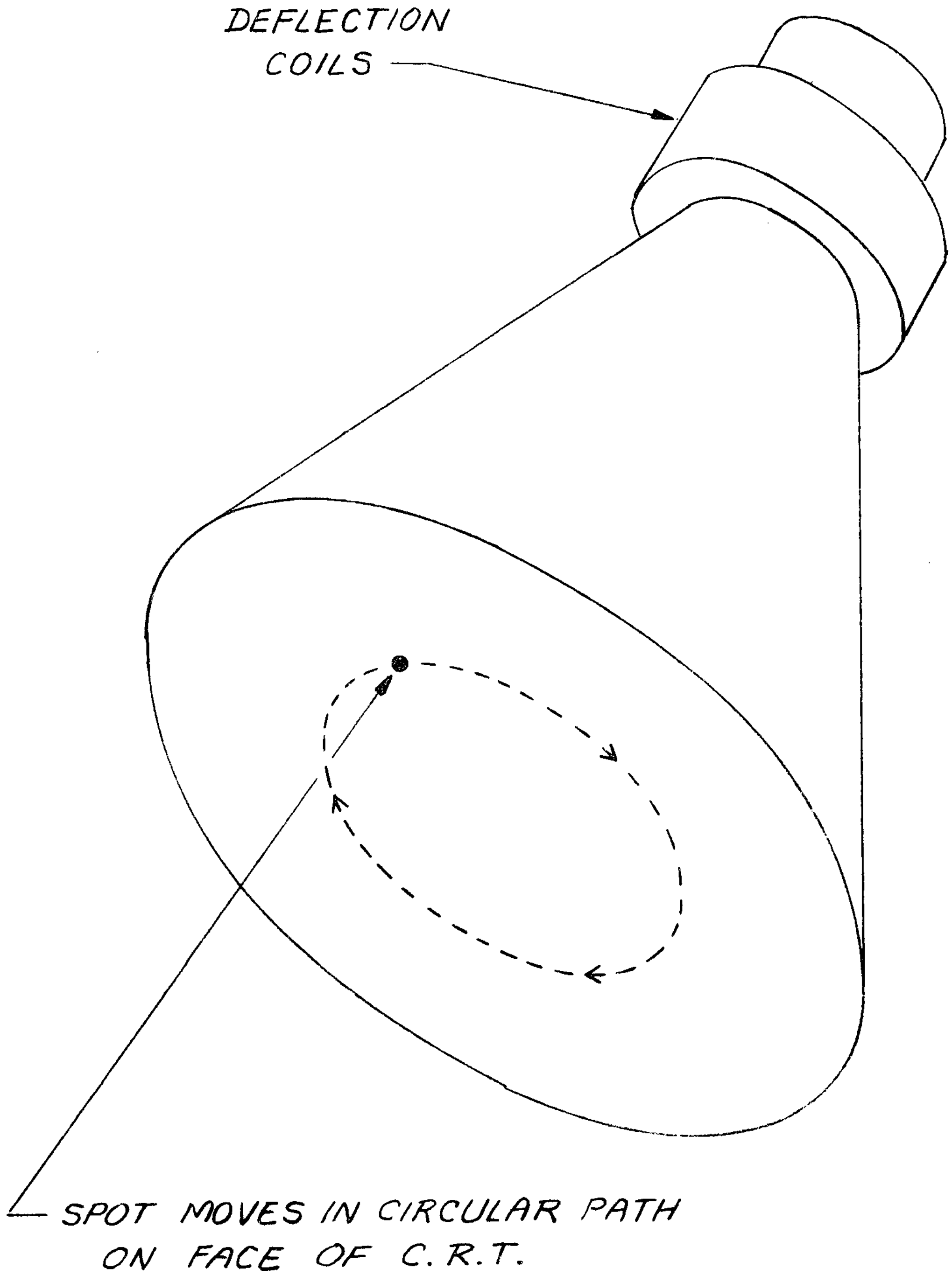

Figure 6. CRT Diagram

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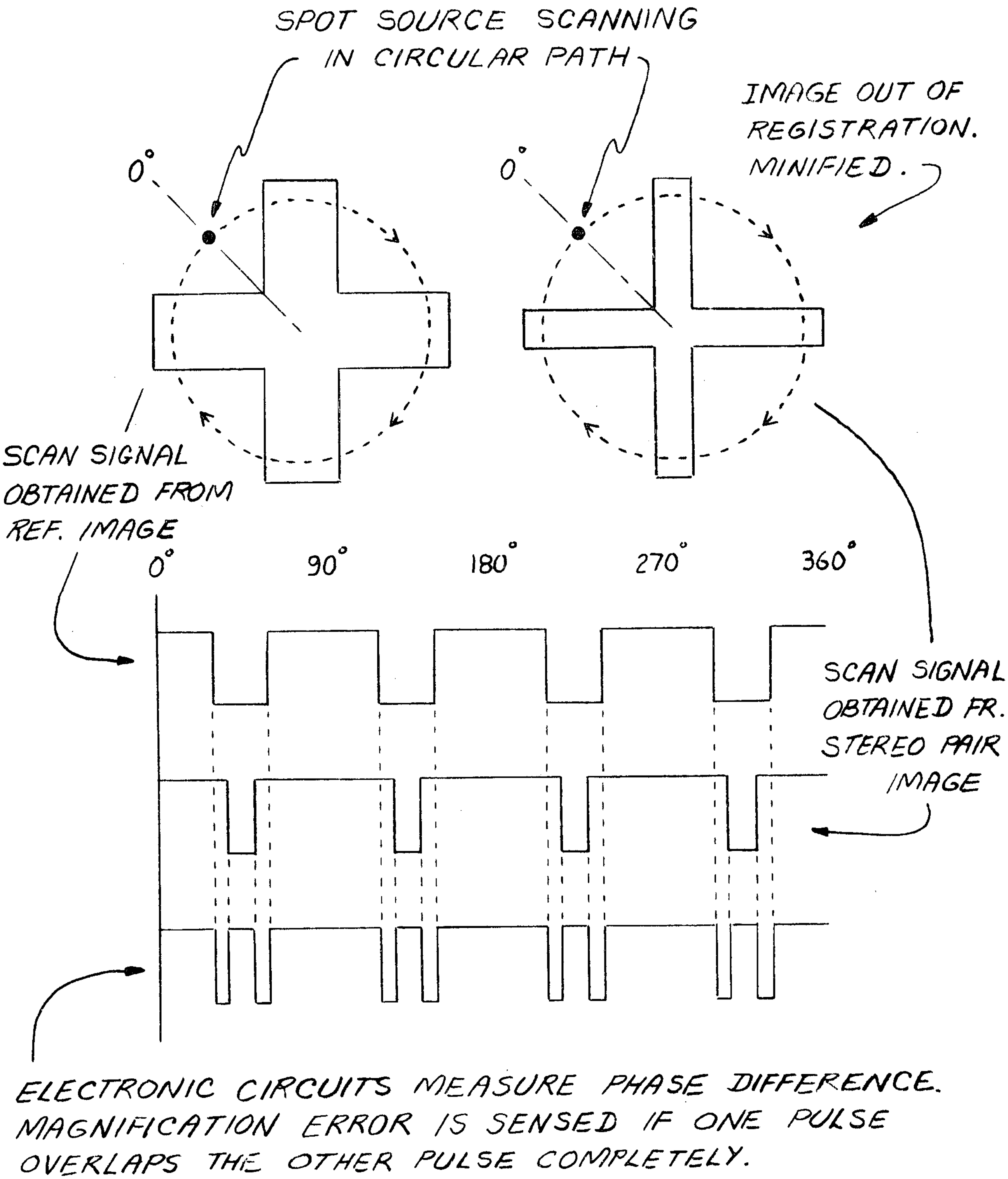

Figure 7. Magnification Error Diagram

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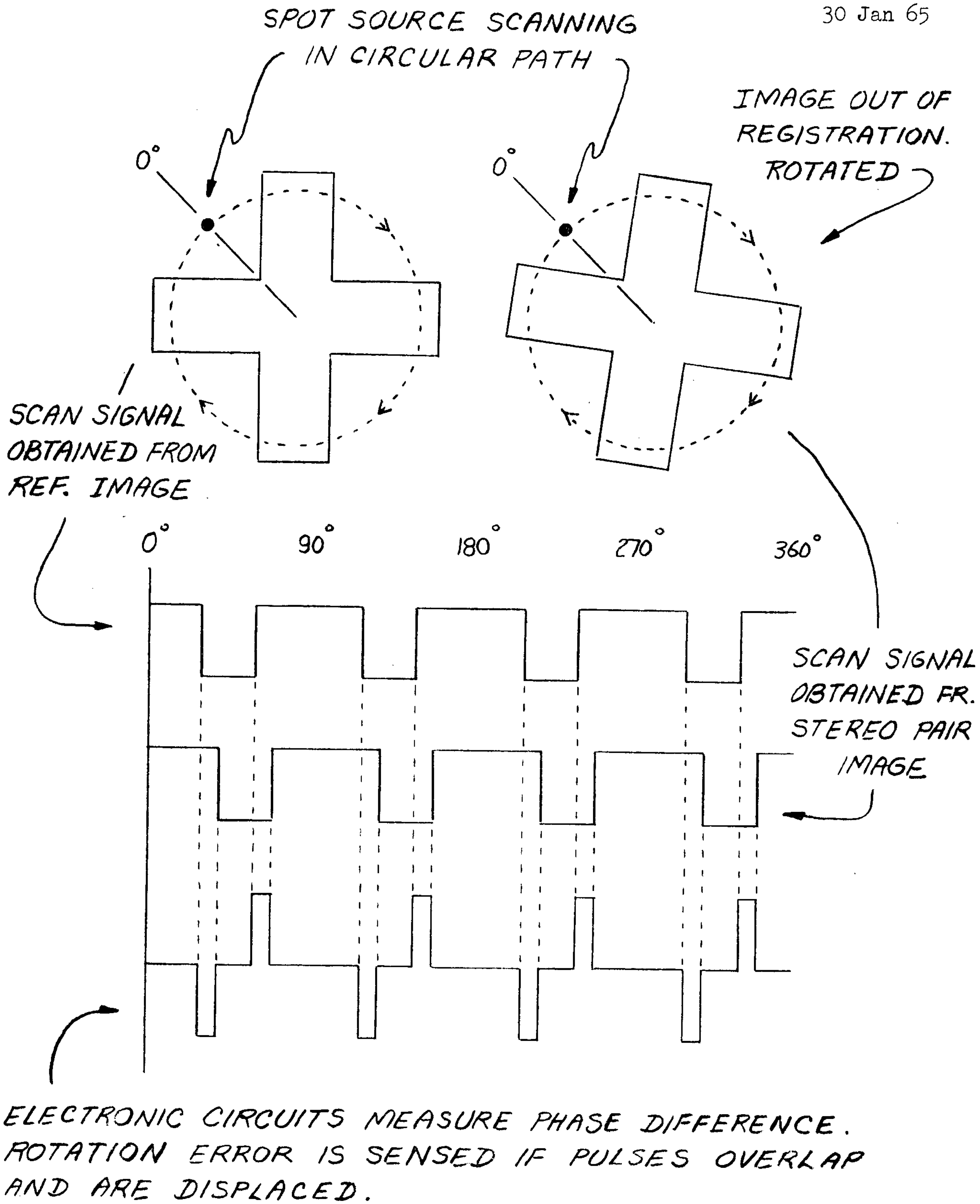

Figure 8. Rotation Error Diagram

(3) The two axis error signals (Figure 9) are obtained in the logic by gating the rotation (θ) error signal with the fixed position sectors of the CRT circle scan. For example: If the stereo pair image is displaced vertically upward (Figure 9) with respect to the reference image, the signal obtained from the reference image will (assuming the spot rotates clockwise) be lagging in phase over the 90° to 180° quadrant of the circle (right-hand side of images). Also, the reference signal will be leading in phase over the 270° to 360° quadrant (left-hand side of images). This alternation of signal phase of the two quadrants on the X axis is a measurement of magnitude and direction of Y displacement error.

5. <u>Breadboard Operation:</u>

a. <u>Head End</u>: This includes the electro-optical system which generates the scan and the scan signals that are delivered to the logic.

(1) The breadboard uses a flying spot CRT Type 5ZP16 with an ultor potential of 20KV. Magnetic deflection coils control the beam position. Each axis coil is driven by a pair of push-pull emitter followers. The circle pattern is obtained by shifting the coil waveforms (60 cps sine wave) 90 degrees with respect to each other. Spot size is controlled by focus potential while intensity is controlled by negative grid bias.

(2) The signal detectors are 10-stage PM tubes. The PM output signal is a-c coupled to a Darlington emitter follower and the PM gain is a function of anode potential. Selected tubes were employed to compensate for optical deficiencies to attain approximately equal signal amplitudes.

(3) The above signals are a-c coupled to the logic with a low frequency cut-off of two cps by class A amplifiers. Individual amplifier gain controls allow signal amplitude matching and signal level adjustment required by the logic.

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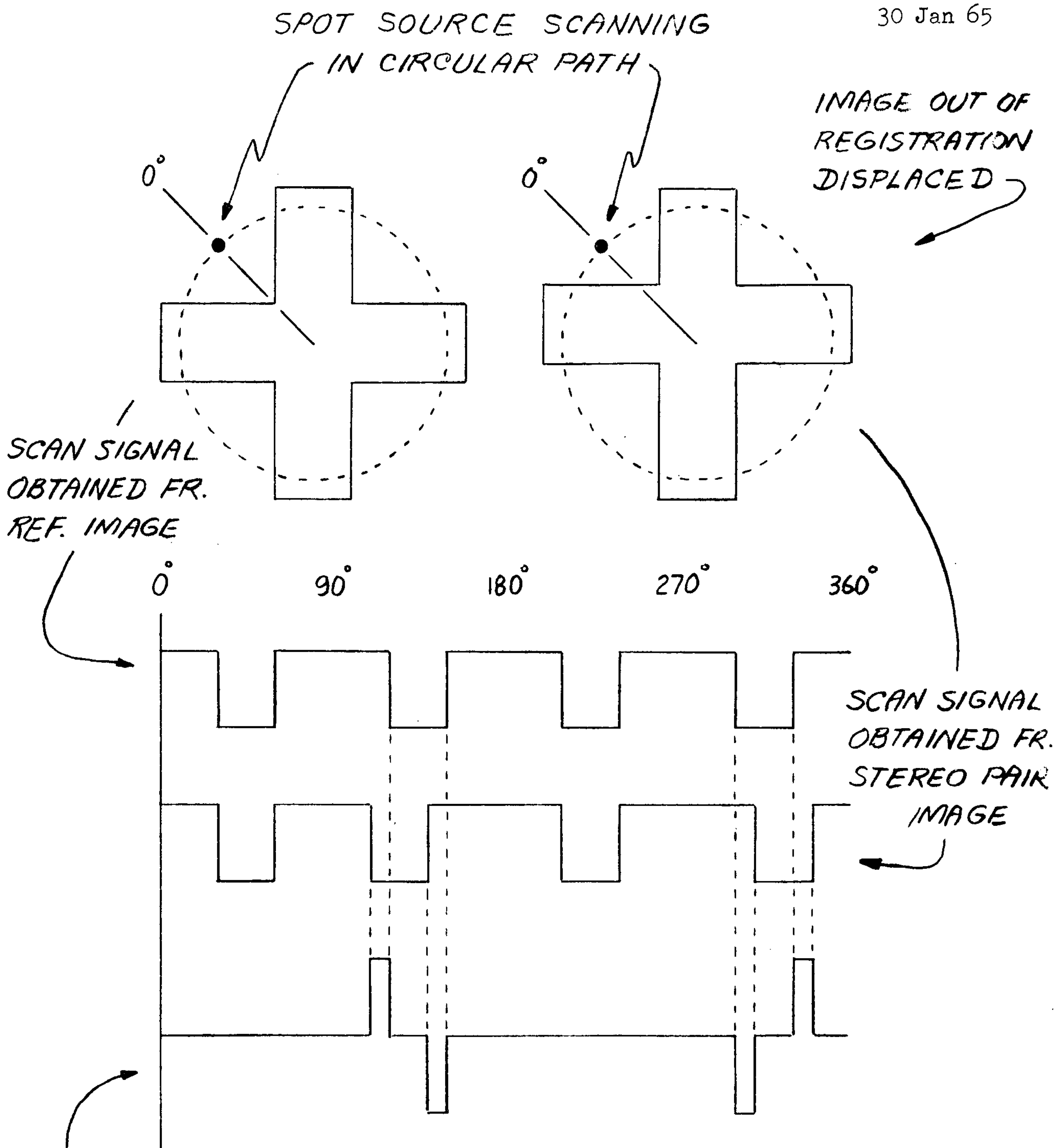

ELECTRONIC CIRCUITS MEASURE PHASE DIFFERENCE. DISPLACEMENT ERROR IS SENSED IF ROTATION ERROR CHANGES PHASE IN ONE AXIS.

Figure 9. Displacement Error Diagram

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b. <u>Logic</u>: Static logic, [redacted] 200 KC S-PAC's, make up the error-detecting logic. This is a NAND type logic shown in block form in Figure 10. 25X1

(1) The shaper circuit, shown here to include the PM amplifiers, accepts the PM signals (a, b) and squares them by use of Schmitt triggers set to detect zero volt crossings. The squared output signals (A, B) and the inverse function ($\overline{A}$, $\overline{B}$) are used by other logic blocks.

(2) The sequencer extracts the pulse phase difference signals digitally. Gates $\overline{1}$ and $\overline{2}$ are enabled until signals A and B are "anded" and gates $\overline{3}$ and $\overline{4}$ are enabled by the anding of A and B for the duration of either A or B. Feeding each gate with the signal and its opposite scan "not" function ($A\overline{B}$, $B\overline{A}$) insures pulse transmission through the gate only if pulses overlap. This feature eliminates single channel noise pulses. The gate output pulses denote phase relation and magnitude of the leading and lagging edges of the two scan pulses A and B.

(a) Pulse $\overline{1}$ indicates A precedes B.

(b) Pulse $\overline{2}$ indicates B precedes A.

(c) Pulse $\overline{3}$ indicates A trails B.

(d) Pulse $\overline{4}$ indicates B trails A.

(3) The decoder combines the sequencer gate signals to determine magnification or rotation error. For example: If A is more magnified than B, A should precede and trail B. Hence, if pulses $\overline{1}$ and $\overline{3}$ occur during pulse sampling, a positive magnification error (M) is present. Again for example: If A leads B, then pulses $\overline{1}$ and $\overline{4}$ should occur indicating a leading (L) error. Make note of the fact that the decoder gates are of the OR variety and pulse $\overline{1}$ is common to both examples. Should only pulse $\overline{1}$ occur, this will indicate both a magnification and a rotation error are present.

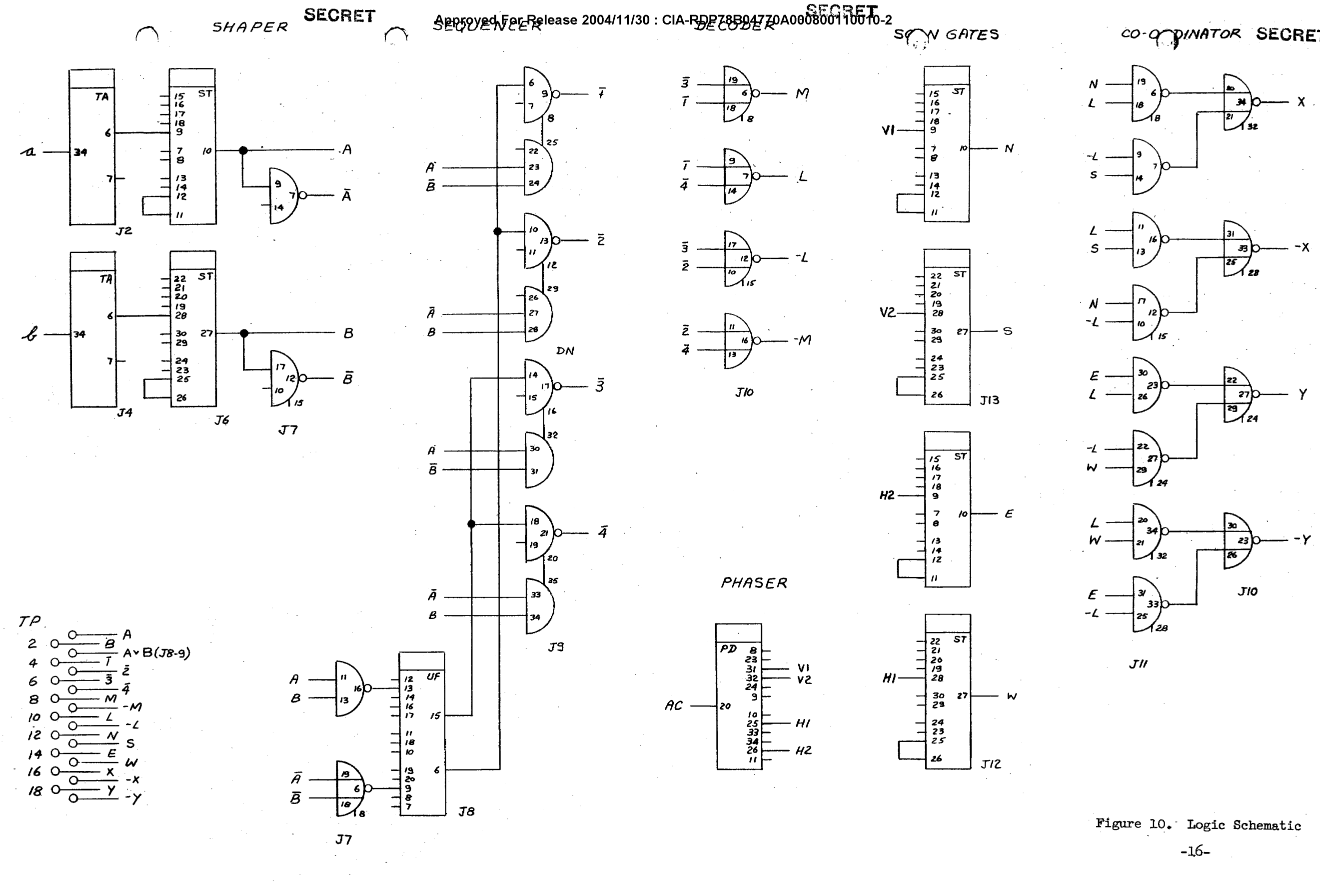

Figure 10. Logic Schematic

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(4) The scan gates are tied into the CRT deflection coil circuits to provide synchronized sector gates for the logic as a function of CRT spot location. These gates provide X and Y axis error determination from rotation error information.

(5) The co-ordinator combines the rotation error signals (L, -L) with the scan gates to determine X and Y axis error. For example: If a leading error (L) occurs during the scan circle crossing of the +Y axis (N sector gate), and a lagging error (-L) occurs during the scan circle crossing of the -Y axis (S sector gate), then a "+X" axis error is present, note the cancellation effect in rotation error when integrated over a single scan interval.

c. Accessory Equipment:

(1) Four ±50 microammeters are connected across the logic error output lines. The logic digital output is 0 volts for no error and -6 volts when sensing error. Meter scale deflection is a function of the time integrated output level. Full scale deflection occurs at maximum error. Scale switches on each meter permit a sensitivity increase by a factor of five for fine adjustments.

(2) Five power supplies service the system:

(a) Logic: -18, -6, and +12 volt.

(b) PM tube: -1500 volt adjustable.

(c) Sorensen: 6.3 VAC CRT filament.
+200 volt CRT grid #2.
-70 volt CRT grid #1 intensity adjustment.

(d) High voltage: CRT Ultor (Variac Adjust).
CRT Focus adjustable.

(e) Viewing lamps: 120 VDC

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(3) One of the stereo images remains fixed in position and is used as the reference image. The other image is adjustable in position with the aid of a microscope positioner table. The table has three degrees of freedom: X, Y, and θ (rotation). Vernier adjustments permit X and Y positioning to 0.0001 inch and θ positioning to one minute.

(4) Portable test equipment included two items: A vacuum tube voltmeter with a high voltage probe to measure the CRT ultor potential and a dual channel oscilloscope to observe signal waveforms.

DISCUSSION

6. Optical Alignment: A collimator was used to establish surface perpendicularity and optical axis alignment between the CRT and the PM. Scan illumination uniformity to both PM tubes was enhanced by masking the optical path to reduce stray light. The lens was focused by observing the PM signal while scanning a well-defined edge. Best focus is attained when the rise time is at a minimum. The scanning circle quadrants were established and related to the logic by scanning a cross pattern. Equal pulse widths and intervals occur when the cross is centered in the optical axis. With the cross aligned in the X and Y axis, the CRT yoke coil was rotated until the signal pulse generated when scanning the +Y axis fell in the center of the N (North) sector gate.

7. Signal Effects: The PM signal depends upon many variables. In general, the signal amplitude level is proportional to the instantaneous scanning spot transmission of the negative. Included in the signal are noise components such as: illumination variation, dirt in the optics, PM jitter, and circuit noise.

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a. The frequency content of the signal depends upon spot size and image resolution. Selected images with geometric patterns (such as airport runways) are easier to recognize visually and electrically than random images such as city buildings. The logic operates very well on selected images.

b. The two scanned images must be overlapping or cover similar area to attain signal correlation. This requires initial manual stereo alignment of the images. Defocusing the CRT spot reduces the alignment sensitivity since the spot encompasses more area on the image.

c. Spot size has a direct effect upon positioning accuracy. A small spot size results in much better positioning accuracy since its resolution capability is enhanced. Actual use of the equipment resulted in adjusting the spot size according to image spatial frequency content.

d. Channel interaction on each scan signal in unavoidable. Moving the scan circle along any axis causes some component change in the other axis.

8. Sensitivity: Image positioning on the breadboard works very well when using selected targets. Image position is repeatable to a fraction of a degree in rotation, and a few thousands of an inch along axis. Day-to-day repeatability is subject to optical stability.

a. Random targets present serious problems. The initial problem is aligning the images in the optical axis. This is done visually to start. The image is then scanned with a defocused spot, and an attempt is made to align the images using meter readings and scope signal observations while reducing spot size. In many instances, some parts of the two scan signals presented on the scope were correlated but other parts of these same signals were uncorrelated. A system has to be devised which will insure that the two scan paths are generating signals representing the same relative parts of the two prints.

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b. Typical scan waveforms are shown in Figures 11 through 14. All except Figure 14 represent PM signals. Note the problem associated with establishing triggering levels for the logic. Figure 13 represents the PM signals and Figure 14, the associated squared signal generated at the zero volts crossing of the PM signal. A slight shift in the d-c detection level of the PM signal can produce a differently shaped output signal which will result in a different error detection output. To develop a successful registration system, an electronic circuit which employs all the content of the complex scan signal instead of just the zero crossings will have to be employed.

CONCLUSIONS

9. Although the present breadboard demonstrates the possibility of a workable system, there remain several problems that need to be solved to obtain an acceptable stereo registration operating apparatus. The principle of measuring phase difference of two circular scan signals (or possibly a spiral scan to obtain area coverage) is thought to be valid. This approach should result in a workable system after the problem of extracting phase correlation is solved. Further study or development is recommended in the following areas.

a. Scanning Spot Size: The optimum spot size for this apparatus is affected by several factors. The spot size employed greatly affects the accuracy of performance and the accuracy with which it is necessary to align the optical system. The relation between spot size and scale of photography, stereo base, and picture content must be investigated and understood to specify the optimum spot size.

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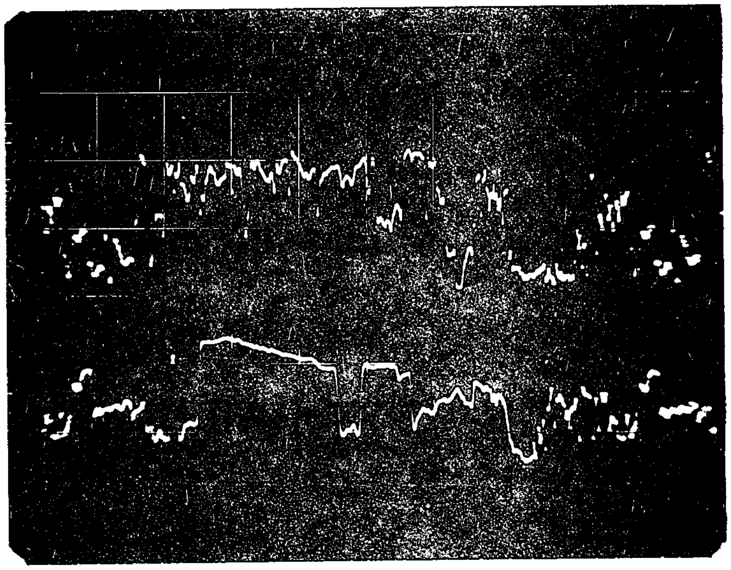

Figure 11. Typical Scene Signals

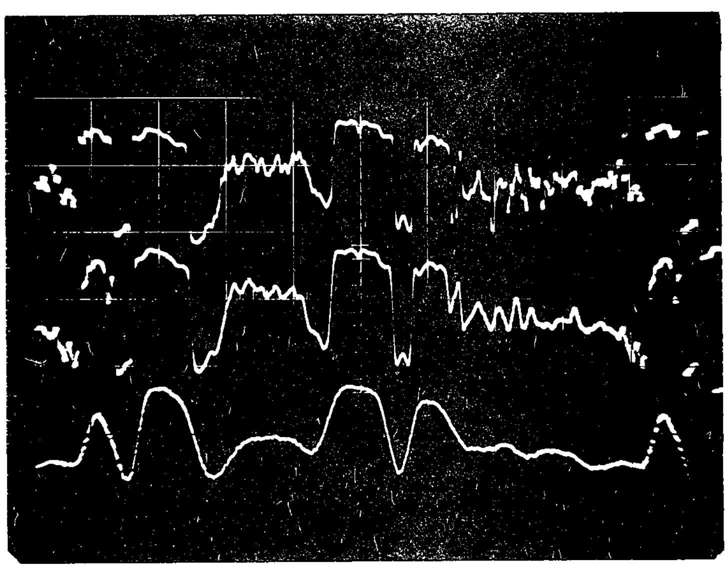

Figure 12. Scene Signals with Spot De-Focusing

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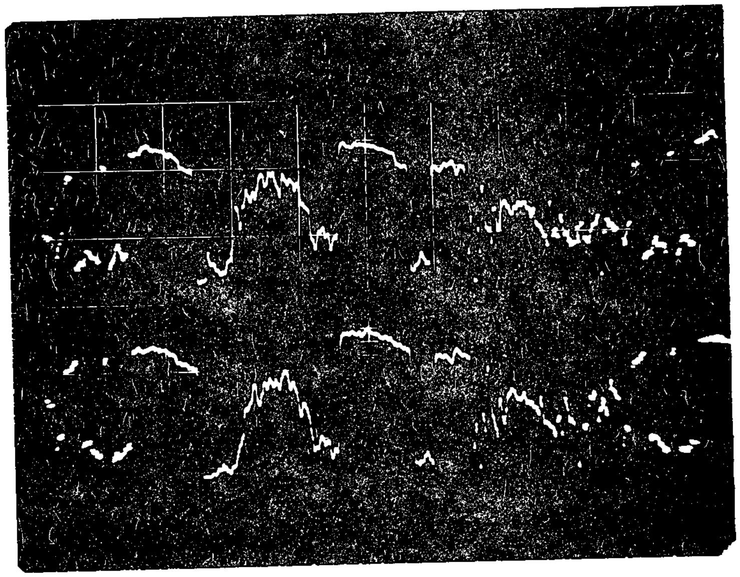

Figure 13. Dual Channel Scene Signals

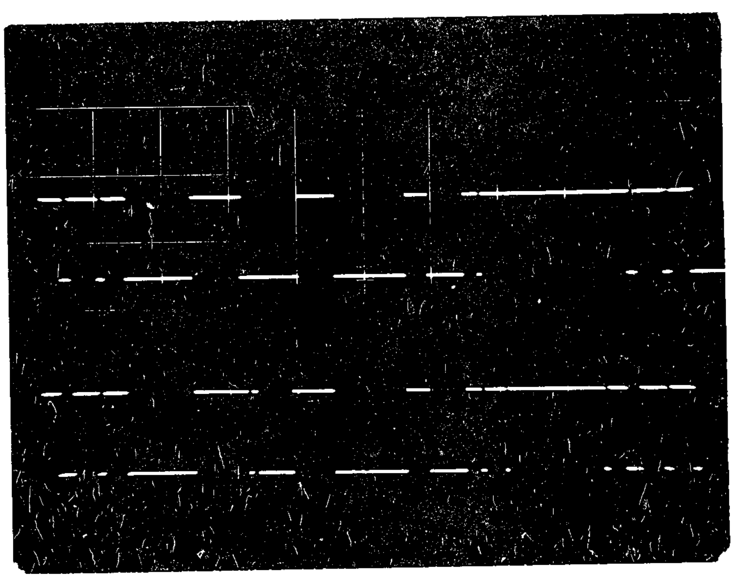

Figure 14. Dual Channel Logic Squared Signals

(1) Since the two stereo negatives are different in their fine detail (to obtain the stereo effect), it is probably necessary to employ a spot large enough to average these differences. Too small a spot would result in erroneous output signals from the logic caused by the sensitivity of the phase measuring circuits.

(2) If one path on the breadboard is tilted with respect to the other optical path, one projected scanning circle on the image will be slightly elliptical. If the elliptical difference is larger than the spot size, the same relative points on the negatives will not be scanned; thus making correlation impossible. The spot size should be large enough to encompass the optical path difference to eliminate this type of error.

(3) The optimum spot size is also affected by the spatial frequency content of the particular print. A large spot scanning a scene such as a city block having small detail would yield little information. A small spot scanning this same scene would yield an abundant amount of information; however, this presents a problem of determining what frequency or frequencies should be extracted from the signal for use in detecting phase error. A low spatial frequency scene on the other hand would probably yield good results when scanned with either small or large spot size.

b. Scanning Circle Size: The optimum scanning circle size must be investigated. For any particular spot size and spot velocity, the information content of the scan signal decreases as the scan circle diameter is lessened. The observer requires stereo registration of the material within his field of view, hence scan registration must occur here. Also, it seems that other scan formats must be investigated which may offer the advantage of higher information content by scanning an area. A spiral or diminishing circle is one suggestion.

c. Signal Amplifier Response: Amplifiers that produce at their output, signals with various weighting of signal amplitude and differentiation should be investigated. These should include true differentiating circuits and limited frequency response amplifiers.

(1) The present amplifiers yield reliable phase-difference measurements of the two signals if the picture content of the negative produces a square wave-like signal shape. The zero-volt axis crossings of this type of signal are clearly defined. Conversely, if the scan signal has the characteristic of a triangular-like wave shape, the zero-volt axis crossings are poorly defined. This condition results in poorly defined phase difference measurements between the two scan signals.

(2) Differentiation of the triangular-shaped wave for instance would produce a signal with good zero-axis crossing detection. This indicates that some signals provide good error detection if the straight amplitude signal is used by the logic, whereas other signals will perform well if differentiated before application to the logic. A final optimum situation will possibly be a combination of amplitude and differentiated signal.

(3) Other signal processing methods should be investigated. The scan signal is extremely complex because its magnitude and waveshape can vary throughout the wide range of image limitation. The signal must either be severely restricted (bandwidth and magnitude) or the circuitry must be very complex. A mathematical analysis would help indicate the proper approach.

(4) Present erroneous signals in the logic contribute to misleading correction output signals. The lower signal of Figure 14, at 2.1 and 3.6 cm to the right of center, illustrates some of these spurious pulses which must be ignored or removed. The same relative pulses do not exist in the upper signal of Figure 14.

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RECOMMENDATIONS

10. To obtain an effective stereo registration system, a more powerful signal processing technique must be developed to determine (or recognize) registration error from the scan signal. The results of efforts to date, while successful for test and selected image pairs, clearly indicated the need for considerable refinement to extract meaningful registration data from random stereo image pairs.

a. Mathematical analysis of the scan signal, by breaking down the complex signal into its various fundamental components, should be initiated. By concentrating only on the components contributing to phase relation, circuitry can be designed intelligently, and the breadboard can be revised according to the mathematical findings.

b. Further investigation is required to determine the most effective scan format. The type of scanning format (circle or spiral), size of scanning format, and size of scanning spot must be defined. These should be selected to yield maximum phase information in the signal scan while tolerating the differences encountered in visually acceptable stereo image pairs. Separate mathematical analysis of each scan format will have to be calculated because the signal waveshape is directly affected by the format.

c. Other methods of signal cross correlation should be investigated.

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